A STUDY OF THE EFFECTS OF CONSTRUCTION VARIABLES ON SOILING CHARACTERISTICS OF FABRICS

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A STUDY OF THE EFFECTS OF CONSTRUCTION VARIABLES

ON SOILING CHARACTERISTICS OF FABRICS

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DEDICATION

This thesis is dedicated to my parents, Bernard and Bernice Schreier, whose love and guidance is the source of my success.

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SUMMARY

Commercially available soil cloths which are used to evaluate the effectiveness of washing machines, detergents, and other components of wet cleaning systems, have been found to exhibit large variations in apparent soiling. These large variations require that the amount of soiling be measured prior to cleaning so that the effect of cleaning on soil removal can be determined. An analysis of soil cloths exhibiting differences in apparent soiling, indicated variations in several yarn and fabric construction characteristics associated with soiling differences. Specifically, variations in yarn count, yarn twist, and yarn crimp were found.

Experimental fabrics were produced in which filling yarn count, filling yarn twist, and filling yarn crimp were varied. Variables were not incorporated in the warp yarns because of the difficulty of producing a large number of warps. Filling yarns were spun at three twist levels and in three yarn counts. Fabrics were woven under appropriate conditions to produce two filling crimp levels for each combination of filling yarn variables.

A method of applying synthetic soil uniformly to a fabric was developed. Each of the experimental fabrics was soiled, and the apparent soil was measured by light reflectance. The soiled fabrics were laundered and the apparent soiling was measured again. The soiled fabrics were also examined microscopically.

The test results indicated that filling yarn crimp was associated with statistically significant soiling differences, with the fabric having a greater amount of crimp having a greater apparent soiling. Neither yarn twist nor yarn count was associated with differences in soiling. A difference in apparent soil was also seen with different crimp levels after laundering the soiled samples, except that the fabrics having greater crimp were cleaner. Microscopic examinations indicated that soil particle deposition correlated with the apparent soiling differences.

CHAPTER I

INTRODUCTION

The problem of fabric soiling and its evaluation has been addressed for many years. During this time, soil cloths with soil uniformly applied have been used as tools of research. Because known amounts of soil were applied, the effects of laundering could be determined. The soil cloth which prompted this study evolved as a result of many experiments. The objectives of past experiments were to answer questions such as:

- -What soil constitutes "natural" soil?
- -What is a reproducible and accurate simulation of soil application?
- -How can soiling and soil removal be evaluated quantitatively?

The question of soil choice was answered by looking at natural soil. Natural soil consists chiefly of fine-grained pigments, fats and stains which are sometimes present singly, but often occur in a mixture.[13] Various soils that have been used in experimentation are lampblack, soot, vacuum cleaner dirt, clay, and Oil Dag.

While the earlier soils (lampblack) were used to reproduce the black color of dirt, later soils were actual soil particles such as soot and vacuum cleaner dirt. The actual soil particles are obtained from particulate soils, windblown fragments of topsoil, or incomplete products of combustion from homes, industry, or various forms of transportation.[4]

Clay has been used because electron micrographs strongly suggest that under end-use conditions, clay minerals are the major particulate materials that contribute to soil buildup on textile fibers.[8]

Particle size uniformity, as well as ease of laboratory reproducibility have led to the use of Oil Dag solutions. Size uniformity is an important factor, as the difficulty in removing particulate soils is related to how small they are.[8]

It is important for research purposes that soil application was reproducible. Also, it was desirable that experimental applications simulated end-use soiling. End-use soiling, however, occurs in different ways. Most particle soiling occurs by brushing or rubbing against a surface where these particles have settled.[8] For example, the brown stains on the inside of shirt cuffs and collars result from constant abrasion between fabric and skin and the resulting deposit of dirt particles, lipids from the skin surface, and pigments in the skin cells on the garment.

Another type of soiling results from contact with a liquid dispersion of soiling matter.[11] Sebum is this type of soiling matter. Sebum is in an emulsified state on the skin surface and can be either an oil-in-water or water-in-oil emulsion depending on the amount of sweat present at a given time.[8]

Laboratory applications of soil have attempted to reproduce these different types of soiling. One method in which the contact with a liquid dispersion of soiling matter was reproduced was a vacuum cleaner dirt, clay, and water slurry mixture tumbled in a dryer and followed by a triolein soiling. Another laboratory method is the immersion of a fabric in an Oil Dag solution. Contact with soil particles has also been experimentally reproduced by rubbing industrial soot into a piece of clean cotton cloth.[8]

Commercially soiled cloths are generally made from carbon black of a specified fineness and oil. The carbon black is applied on cotton piece goods by immersion either in an aqueous dispersion of carbon black or an organic solvent dispersion of carbon black.

Experts differ in their opinions about the method of soiling that most nearly approximates that of actual use. In the case of underwear, bedclothes, and table linens, it may be assumed that most of the soil reaches the fibrous material from an aqueous solution.[13] Because of the lack of conclusive evidence about the mechanism of soiling, the preferred laboratory method is one which is reproducible and controllable.

After the problems of soiling method and soil type have been addressed, the question of quantifying the amount of soil deposited on a fabric remains. Gravimetric and optical methods have been used to measure this characteristic.

The gravimetric technique involves weighing the material before and after soiling or before and after cleaning.[1] The results are expressed as the mass of soil acquired by a certain quantity of the material.[10] Gravimetric methods are limited since soiling is produced by minute quantities of soil which might increase the weight, but might not cause the fabric to appear soiled. It is the appearance and not the soil content of the textile which is the standard by which cleanliness is judged. Also, hydraulic effects of agitation in laundering may cause a weight loss which includes not only soil loss, but also a loss of fibers in the form of lint.

An optical method for assessing soiling is one in which the intensity of light reflected by the textile material is obtained. To evaluate soiling, the decrease in reflectance units between the initially clean fabric and soiled fabric is determined. The optical method for quantifying soiling also has its limitations. Light scattering equations, such as the Kubelka-Munk equations, are used to measure the amount of soil present. Their use has been criticized because of their failure when applied to reflectance systems. It was thought that the equations were only valid with uniform soil particle distribution. It was also necessary for the specific absorbance of the soil particle to be known.

Another criticism is that when used with textile materials, the linear relationship of the reflectance values against soil content held only for low amounts of soil. With higher soil content values, the reflectance values became less than predicted by linear extrapolation.[3] Further research, however, has indicated that with reflectance values obtained during washing, the equations are valid.

Another consideration is the control of background effects.[10] In any measure of the reflectance of a fabric, the value obtained depends on the reflecting property of the background against which the fabric is placed. An open structured fabric will have light passing through the interstices which would yield a higher value when against a white background rather than a black background.

Also, the extend of change in the appearance of the fabric for a given uptake of soiling matter depends upon the manner in which the soil is distributed in the fabric. Therefore, optical assessment of soiling of a fabric will be different for different soiling conditions. Although optical methods have been criticized, the results of past research have indicated that they are acceptable methods. Since optical methods are also convenient, they are commonly used to quantify soiling and laundering.

Once the questions concerning soil type, soiling procedure, and soiling evaluation have been answered, other problems in the area of soiling can be examined. The subject of this thesis is one such problem.

It has been observed that commercially available soil cloths exhibit varying reflectance values throughout the roll. This variation is a problem because it necessitates the selection of samples from various parts of the fabric for each experiment to insure a uniform basis of soiled fabric from one experiment to another.

One possible explanation for reflectance variations is that there is not a constant amount of soil particles present in the soiling solution during fabric soiling. Once soiling begins, the solution is being depleted. If the solution is not maintained at a constant level, each section of a roll of cloth will be soiled by different amounts of solution. This variation could cause variations in reflectance values.

Also, if the time of contact with the soiling solution is not constant throughout the fabric roll, variations could result. Variations in soiling could be caused by a preferential uptake of either soil or solvent.

Another possible cause of variations is soil migration during the winding up of the wet cloth on rolls. If the cloth is being wound on rolls, a pressure will be exerted upon the preceding layers of fabric causing a migration of soiling solution. This migration also would cause variations in reflectance values.

The variation could also be caused by variation in fabric properties. Such factors as yarn crimp, yarn count, yarn twist, or number of filling picks and warp ends per inch are factors which are considered.

It was believed that unknown yarn or fabric non-uniformities exist which cause the amount of soiling to vary. To further examine the problem, a preliminary examination of two pieces of soil cloth, which were supposed to be identical, was made. Results of the preliminary examination indicated that a variation in yarn crimp, yarn count, and yarn twist existed. The objective of this thesis is to examine the soiling characteristics of a fabric in order to determine the effect of variations in yarn twist and yarn count and variations in fabric crimp on the amount of soiling as measured by reflectance techniques.

CHAPTER II

EXPERIMENTAL PROCEDURE

Weaving

A Hunt loom with a 44" reed space was used to weave the test fabrics incorporating the experimental variables. The warp consisted of 1988 ends of 200 denier polyester filament yarn with five turns per inch of twist. The reed used had 24.7 dents per inch. Two levels of warp tension were used to provide two levels of fabric crimp. To obtain the two warp weaving tensions, the minimum amount of tension which would produce a good fabric was chosen. The second tension level was chosen to be approximately twice that of the first tension level. The two levels of warp tension, as measured by a tension meter, can be seen in Table 1.

Table 1. Warp Tension Levels

Crank Shaft Position	Level 1	Level 2
Back Center (fully opened shed)	24 grams/end	40 grams/end
Front Center (beat up)	55 grams/end	100 grams/end

The yarn twist and yarn count variables were incorporated in the cotton weft yarn. Yarns were spun from homogeneous raw material (roving) at three levels of twist and three yarn sizes. The weft variables can be seen in Table 2. The finished fabric had an average of 45 picks per inch and 58 ends per inch for all filling yarns used. The measurements made to determine filling and warp yarn counts can be seen in Table 3. Approximately two yards of each of the nine yarn samples were woven. At each level of tension, the three filling twists and three yarn counts provided the 18 experimental samples.

The amount of twist was characterized by the twist multiplier (a measure of twist angle) and not the number of turns per inch. Twist multiplier is defined as $\frac{\text{Twist turns per inch}}{(\text{Cotton Count})^{1/2}}$. Thus, for different cotton counts, the turns per inch of twist for the same quantity of twist as measured by twist angle will not be the same.

Scouring and Bleaching

During the scouring and bleaching procedure, motes or dark particles of cellulosic trash remaining in the cloth were removed. To scour the fabrics, a bath was prepared with 400 grams of detergent, 600 grams of sodium carbonate, and 600 grams of sodium hydroxide added to a 300 liter bath in a four foot pilot scale dye beck. The temperature was raised to 100°C., and the fabric was circulated in the bath for one and one half hours. The solution was drained, and the dye beck was refilled with 300 liters of 30°C. water. The sample was rinsed thoroughly.

The fabric was then bleached in a bath containing 300 liters of water at 30°C., 1000 grams of sodium carbonate, and eight quarts of Chlorox (a 5% solution of sodium hypochlorite).

Table 2. Weft Variables

Sample Number	Twist Multiplier	Cotton Count	Warp Tension
1	4.00	17.0	Level 1
2	4.75	17.0	Level 1
3	5.50	17.0	Level 1
4	4.00	19.5	Level 1
5	4.75	19.5	Level 1
6	5.50	19.5	Level 1
7	4.00	22.0	Level 1
8	4.75	22.0	Level 1
9	5.50	22.0	Level 1

Sample Number	Twist Multiplier	Yarn Count	Warp Tension
1'	4.00	17.0	Level 2
2'	4.75	17.0	Level 2
3'	5.50	17.0	Level 2
4'	4.00	19.5	Level 2
5'	4.75	19.5	Level 2
6'	5.50	19.5	Level 2
7'	4.00	22.0	Level 2
8'	4.75	22.0	Level 2
9'	5.50	22.0	Level 2

Table 3. Sample Fabric Characteristics

Sample Number	Picks Per Inch*	Ends Per Inch*
1	46.0	57.8
2	45.0	58.1
3	45.6	58.1
4	44.1	58.6
5	45.1	58.0
6	45.0	58.2
7	44.4	59.0
8	44.7	57.8
9	44.0	57.2
	Average 44.9	Average 58.1
1'	45.8	58.1
2'	45.7	57.6
3'	46.8	56.8
4'	44.5	57.6
5'	45.6	56.5
6'	46.4	57.0
7'	44.6	57.9
8'	44.9	57.2
9'	46.0	57.0
	Average 45.6	Average 57.3

*Each sample reading is an average of 10 measurements made in five different areas.

After the fabric was circulated in this bleaching solution for two hours, the solution was drained. The fabric was rinsed in the dye beck in 300 liters of water at 30°C. The rinse water was drained and the dye beck was refilled with a neutralizing solution.

The solution used to neutralize the cloth contained 25 ml. of concentrated hydrochloric acid and 300 liters of water at 30°C. The fabric was circultated in the dye beck in this solution for 15 minutes after which the solution was drained. After rinsing the fabric in 300 liters of water at 30°C. in the dye beck, 25 grams of sodium bicarbonate were added. The fabric was circulated in the bicarbonate solution for 10 minutes. The solution was drained, and the dye beck was refilled with 300 liters of water so the fabric could be rinsed. To remove residual chlorine, an antichlor treatment of 25 grams of sodium bisulfite was added to the dye beck. After the fabric was rinsed, it was extracted and pressed.

Development of Soiling Method

Before soiling of the experimental fabrics began, the uniformity of soiling within a sample and reliability of soiling repeated after 24 hours was determined. The soiling solution used was an Oil Dag solution whose base components were 1 ml. Oil Dag (graphite), 1 ml. Wesson oil, and 625 ml. perchlorethylene. The soiling solution for the entire experiment was made at one time. An Atlas Laboratory Wringer was used to apply the soil. This piece of equipment can be seen in Figure 1.

To determine the uniformity of soiling, ten 5-1/4" x 37" strips of fabric were soiled individually in 250 ml. of the soiling solution.

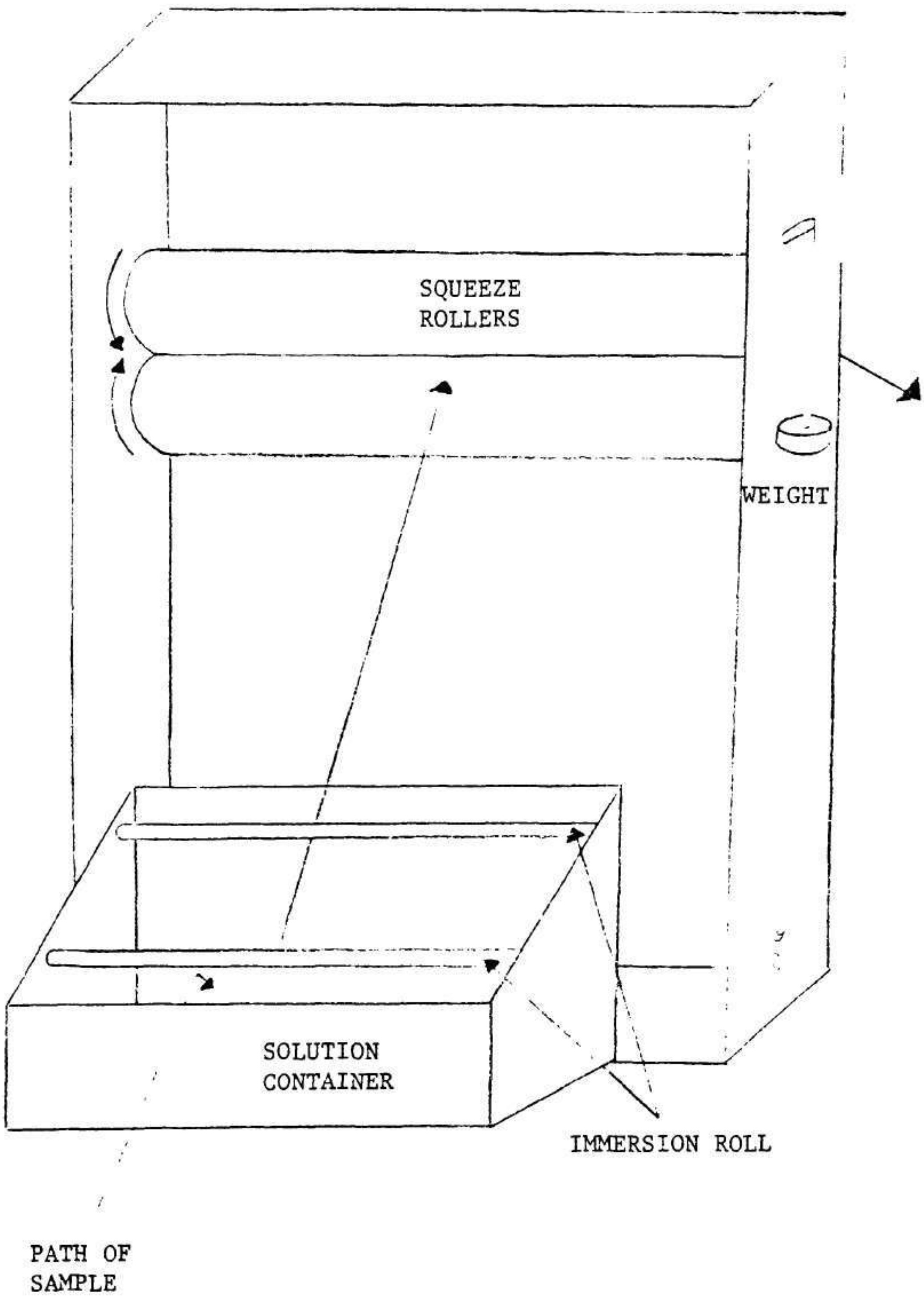


Figure 1. Atlas Laundry Wringer

Samples were cut with the long dimension being in the direction of the warp. To insure uniform soiling time, samples were numbered and inserted under the immersion roll which was lifted out of the bath, with the numbered end first. The sample was not immersed in the soiling solution at this point. The end was then gripped by the wringer as the machine was started. The sample was held back and soiling did not begin until after the immersion roll was put in place and the fabric immersed in the soiling solution. Once soiling began, it proceeded for the same time and at the same pressure. Figure 1 shows a diagram of this procedure.

After each sample was soiled, the soiling solution was removed and replaced with a fresh solution in order to avoid introducing variations associated with concentration. Samples were line dried vertically and hung from the numbered end. Reflectance readings were obtained on the Diano/LSCE AutoMate System at five different areas of each sample. The readings were taken at five-inch intervals on the sample. Two reflectance readings were taken at each location with the sample being removed and replaced after each reading. This procedure was followed to prevent errors due to sample presentation. All readings were made with 16 thicknesses of test fabric behind the test sample to eliminate background effects. Table 4 shows the reflectance results obtained from these samples. The average reflectances for each of the samples appears to be similar.

After 24 hours, reflectance readings were taken again for the same samples to determine the reproducibility of the measuring

Table 4. R_d Values of Soiled Samples Used to Determine Soiling Uniformity

SAMPLE #	LOCATION ON SAMPLE					
	Top	Middle			Bottom	Average
1	43.14	42.24	40.84	40.72	38.24	
	43.98	42.28	40.74	41.36	38.24	41.18
2	42.38	43.30	41.38	40.12	40.38	
	43.40	42.78	41.36	40.48	40.38	41.70
3	43.70	42.04	41.38	40.92	39.60	
	43.66	41.68	41.34	40.92	39.58	41.48
4	43.08	42.70	42.56	42.58	42.34	
	43.08	43.22	42.56	43.58	42.30	42.80
5	42.46	42.28	41.22	40.16	39.44	
	42.68	42.28	41.42	40.00	39.94	41.24
6	43.60	42.38	42.42	41.40	41.50	
	43.60	42.36	42.38	41.52	41.28	42.24
7	43.76	43.02	41.82	41.84	40.10	
	44.06	42.58	41.86	41.84	40.10	42.10
8	43.60	43.06	43.06	41.76	40.20	
	43.72	43.00	43.04	41.62	40.90	42.40
9	39.96	43.40	43.20	43.00	41.58	
	39.88	42.34	43.16	43.00	41.62	42.11
10	44.42	45.16	43.90	42.46	42.18	
	44.42	45.30	43.90	42.36	42.18	43.63

procedure. The results in Table 5 indicate that the reflectance measurements taken after 24 hours were not different from the original measurements. However, it was determined that more work was needed in the drying procedure because of a tendency to increased soiling toward the bottom of the sample. This tendency was indicated by decreased reflectance values as the readings proceeded from the numbered end of the sample to the lower end. A statistical analysis of the data indicated that to achieve a 95% probability level a difference of 0.6 R_d values would be detected, and 25 samples would have to be used. A 95% probability level means that there is a 95% probability that differences observed are a result of the effects of the experimental variables and not a result of chance. Because of the large number of samples that would be required and the non-uniformity of the samples, it was concluded that the drying method was unsatisfactory. The soiling method was thought to be satisfactory because the samples were being soiled for equal amounts of time and under the same pressure.

To see if other types of drying methods would be satisfactory, fifteen 2-3/4" x 22-1/4" samples were used for an evaluation of three types of drying. The samples were soiled as previously described. The vertical method, in which the sample was hung along its width edge from a line, was repeated. A horizontal method in which the samples were hung along their length edge from a line was also evaluated. A flat method in which the samples were attached to nails driven into two 24-inch wood strips at 2-inch intervals was also used. The strips were placed a distance of 18" between the nail boards. After the

Table 5. R_d Values of Soiled Samples Used to Determine Soiling Uniformity, Measured After 24 Hours

SAMPLE #	LOCATION ON SAMPLE					
	Top	Middle			Bottom	Average
1	43.48 43.46	41.78 41.74	41.04 40.66	40.96 40.94	38.12 38.44	41.06
2	43.42 43.42	42.92 43.14	41.36 41.84	40.20 40.34	39.88 39.84	41.64
3	43.74 43.76	42.66 42.16	41.18 41.38	41.02 41.00	40.00 40.00	41.69
4	42.92 42.90	41.94 42.40	42.40 42.26	43.08 42.76	41.98 41.96	42.46
5	42.58 42.56	42.16 42.14	41.62 41.58	40.06 40.00	40.02 40.02	41.27
6	42.80 42.84	42.00 42.92	42.50 42.12	41.66 41.66	41.54 41.38	42.14
7	44.14 44.14	43.00 42.92	42.08 42.08	41.78 41.76	39.90 39.92	46.35
8	43.70 43.58	42.92 42.82	42.88 42.90	41.26 41.28	40.28 40.24	42.68
9	39.72 39.64	43.26 42.88	42.90 42.90	42.70 42.64	41.32 41.28	41.92
10	44.32 44.36	44.94 44.96	43.76 43.76	42.20 42.34	41.82 41.56	43.40

samples were soiled, they were attached to the nails as shown in Figure 2. The samples were kept as flat as possible with minimal sagging. After air drying, reflectance determinations were made at three inch intervals on the samples. In Table 6, it can be seen that samples dried in the vertical plane have greater variability than samples dried in a horizontal plane using the flat method. In the vertical plane, the range of variation was 52.16 to 53.21. The flat method had a range of variation of 52.19 to 52.61. Also, the samples dried in the flat method did not appear to have any systematic increases or decreases in reflectance values. Because of the lower variability, the flat method was determined to be the most suitable of the three methods.

Results indicated that a total of seven samples were needed for the experiment to achieve a significance level of 95% for differences of 0.6 R_d value. A total number of ten samples, five for each of two replications, were used for the soiling experiments. Each replication consisted of the soiling of 90 samples.

Laundering

Each sample was laundered in a Terg-O-Tometer using the standard American Home Appliance Manufacturers' detergent. The detergent solution contained 1.6 grams of detergent per 1000 ml. of water. Temperature of the water was 60°C. The solution was agitated at 75 RPM for 30 seconds to dissolve the detergent. One sample per can was added and washed for 10 minutes. The soap solution was replaced with 1000 ml. of water, and the sample was rinsed for five minutes. The samples were line dried.

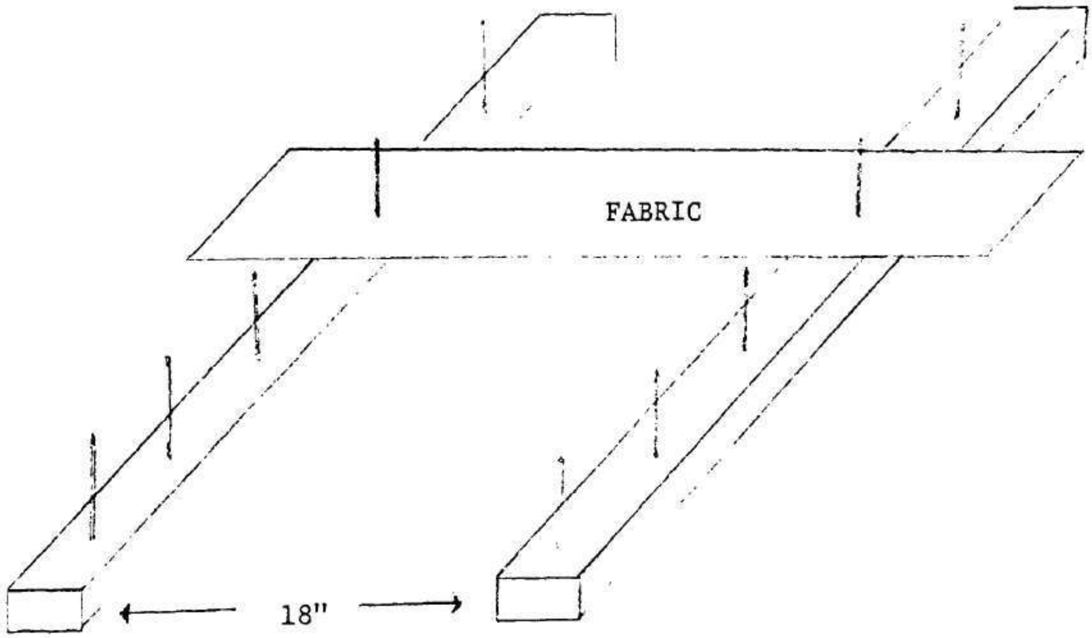


Figure 2. Nail Boards for Sample Drying

Table 6. R_d Values of Samples from the Various Drying Methods

Method of Drying	Sample Number	Location on Sample: Top	Middle		Bottom	Average
VERTICAL DIRECTION	1	53.62 53.58	53.72 52.88	53.38 53.40	51.51 51.49	53.12
	2	53.84 53.82	51.28 51.30	51.04 51.72	51.01 52.03	52.08
	3	52.88 52.88	52.94 52.92	52.26 52.24	51.12 51.06	52.29
	4	54.02 54.04	53.60 53.68	52.26 52.20	52.18 52.18	53.02
	5	53.26 53.08	53.04 53.00	52.98 53.00	52.30 52.34	52.88
HORIZONTAL DIRECTION	6	53.24 53.24	54.02 54.06	53.00 53.00	52.58 52.56	53.21
	7	52.20 52.22	52.24 52.34	51.98 51.96	52.54 52.58	52.26
	8	52.98 52.96	52.94 52.96	52.28 52.24	52.22 52.20	52.60
	9	52.96 52.98	53.00 53.02	53.38 52.40	52.54 52.84	52.89
	10	52.64 52.54	52.52 52.50	51.72 51.70	51.82 51.84	52.16
FLAT	11	52.58 52.54	52.32 52.26	52.26 52.10	52.08 52.06	52.28
	12	52.92 52.90	52.66 62.66	51.80 51.82	52.56 52.58	52.49
	13	53.94 53.90	52.14 52.10	52.28 52.26	52.24 52.04	52.61
	14	52.30 52.28	52.26 52.10	52.10 52.12	52.20 52.18	52.19
	15	52.82 52.84	52.42 52.42	52.44 52.48	51.88 51.90	52.40

Yarn Twist, Yarn Count, and Yarn Crimp

The experimental yarns were tested to determine the actual amounts of twist. Twist determinations were made using the untwist-retwist method (ASTM Method D-1422-71). Yarn count was determined according to ASTM Method D-1907-75. The yarn count and twist measurements are shown in Table 7.

Filling crimp was determined by measuring the number of ends per inch in the reed and the number of ends per inch in the fabric. Crimp was calculated as:

$$\left(\frac{\text{ends/inch in fabric}}{\text{ends/inch in reed}} - 1\right) \times 100.$$

The results of yarn twist, yarn count, and filling crimp determinations can be seen in Table 7.

Microscopic Determinations

A Mini SEM scanning Electron microscope was used for microscopic examination of the soiled samples. The samples were mounted and coated with a gold-palladium alloy. The SEM was equipped with a Polaroid camera which was used for all photographs. The film used was Polaroid Type 52 film.

Table 7. Experimentally Determined Values of Yarn and Fabric Variables

Sample Number	Filling Crimp, %	Cotton Count	Yarn Twist, TPI
1	17.00	17.2	16.9
2	17.61	17.6	14.0
3	17.61	16.7	20.0
4	18.62	20.4	15.7
5	17.41	19.1	19.2
6	17.81	18.8	22.3
7	19.43	22.2	15.9
8	17.00	21.7	20.0
9	15.79	20.6	22.2
1'	17.61		
2'	16.60		
3'	14.98		
4'	16.60		
5'	14.14		
6'	15.39		
7'	17.21		
8'	15.79		
9'	15.39		

Overall Averages:

COTTON COUNT	17.2	19.4	21.5
TWIST MULTIPLIER	4.00	4.75	5.50
	16.2 TPI	17.7 TPI	21.5 TPI
FILLING CRIMP	Level 1	Level 2	
	17.6%	16.0%	

CHAPTER III

RESULTS AND DISCUSSION

It can be seen in Table 8 that the unsoiled samples incorporating all of the variables appear to be the same according to reflectance readings. This conclusion was based on the color difference function used in the development of the Simon and Goodwin Color Difference Calculating Chart.[12] Results obtained with these charts indicated that a reflectance difference greater than 0.6 R_d value between two sample groups is considered visually different. The fabrics of varying yarn twists, yarn counts, and filling crimp were not significantly different when examined by eye or by reflectance.

After soiling, the test results indicated that samples with different filling yarn crimp were significantly different statistically with a 95% probability. The reflectance values of samples having different filling crimp were significantly different at a 95% probability level based on an F ratio of 6.89. Statistically significant differences were also seen with different crimp levels after the soiled samples were laundered. The samples having different yarn twists and different yarn counts were not different, statistically. The reflectance values after soiling and after laundering can be seen in Tables 9 and 10.

When yarn crimp was determined for each of the test fabrics, it was found that the higher warp tension used in Crimp Level 2 produced

Table 8. R_d Values of Fabric Samples Before Soiling

Sample Number[1]	R_d[2]	Sample Number[1]	R_d[2]
1	88.27	1'	86.60
2	88.60	2'	87.04
3	87.14	3'	85.94
4	88.09	4'	86.70
5	87.58	5'	86.66
6	86.56	6'	87.42
7	87.34	7'	87.91
8	86.88	8'	87.20
9	86.19	9'	86.41

Average R_d Values:

		R_d
FILLING CRIMP		
	Level 1 (17.6%)	87.40
	Level 2 (16.0%)	86.87
YARN COUNT		
	17.0	86.93
	19.5	87.17
	22.0	87.09
TWIST MULTIPLIER		
	4.00	87.49
	4.75	87.33
	5.50	86.71

[1]Refer to Table 2 for identification of variable.

[2]Each number represents the average 100 reflectance measurements.

Table 9. R_d Values of Fabric Samples After Soiling

Sample Number[1]	R_d [2]	Sample Number[1]	R_d [2]
1	40.29	1'	41.76
2	40.76	2'	42.32
3	40.33	3'	41.32
4	40.56	4'	41.86
5	40.55	5'	42.39
6	39.75	6'	41.70
7	40.11	7'	40.58
8	41.07	8'	41.65
9	40.97	9'	41.11

Average R_d Values:	R_d
FILLING CRIMP	
17.6%	40.48[3]
16.0%	41.55[3]
YARN COUNT	
17.0	41.1
19.5	41.1
22.0	40.8
TWIST MULTIPLIER	
4.00	40.9
4.75	41.4
5.50	40.9

[1] Refer to Table 2 for identification of variables.

[2] Each number represents the average of 100 reflectance measurements.

[3] Statistically significant at a 95% probability level.

Table 10. R_d Values of Fabric Samples After Laundering

Sample Number[1]	R_d	Sample Number[1]	R_d
1	49.82	1'	49.80
2	52.92	2'	51.73
3	52.06	3'	49.46
4	54.14	4'	54.86
5	52.82	5'	50.95
6	52.06	6'	48.34
7	53.49	7'	50.22
8	53.68	8'	50.62
9	52.30	9'	49.31

Average R_d Values:	R_d
FILLING CRIMP	
17.6%	52.70[3]
16.0%	50.58[3]
YARN COUNT	
17.0	50.97
19.5	52.19
22.0	51.76
TWIST MULTIPLIER	
4.00	52.22
4.75	52.12
5.50	50.59

[1]Refer to Table 2 for identification of variables.

[2]Each number represents the average of 100 reflectance measurements.

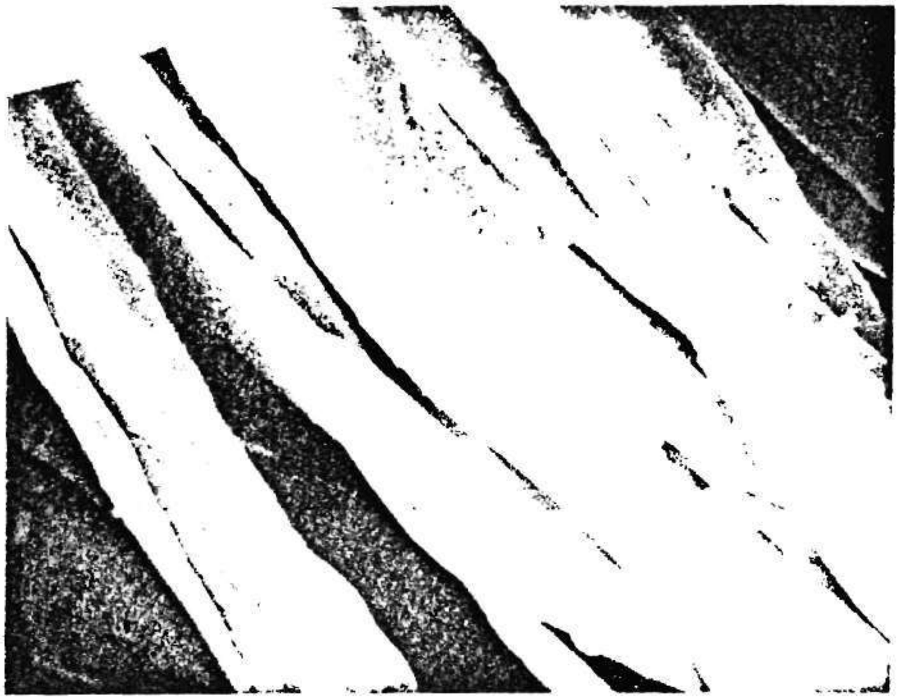
[3]Statistically significant at a 95% probability level.

samples of less filling crimp. This was not expected as the greater warp tension in Level 2 should have produced samples of greater filling crimp. It was thought that the cause of the reversal was the filling winding off tension or warp tension which might have varied during weaving. After soiling, the samples with less crimp were cleaner. After laundering, however, the samples with greater crimp were cleaner.

As a result of microscopic examination of the soiled samples, pictures were obtained which provided additional information. At a magnification of 1000 times, soil distribution appeared uniform between samples of the same tension. Particles were visible on both the polyester and cotton yarns, as can be seen in Figure 3. More soil particles can be seen on the fabric having the greater filling crimp. The results from the microscopic observation are in agreement with the results found in Table 9. After soiling, the average reflectance values of fabrics with greater crimp is lower than that of fabrics with less crimp.

To explain the causes of reflectance differences found, it is necessary to examine other factors which may affect reflectance of light from fabric surfaces.

Geometrical properties of yarns and fibers exert a large influence on fabric properties. The interstices between yarns and spaces between fibers provide areas for soil to become lodged. This trapped soil affects the color of the fabric that is perceived. Also, yarns of different sizes and cross sections will provide different sized open areas for the soil to become trapped. Fiber and yarn size and shape are not the only determinants of color perception, however.



High Crimp Level (Cotton Fibers in Sample 1 Magnified 1000x at 0°)

Low Crimp Level (Cotton Fibers in Sample 1' Magnified 1000x at 0°)

Figure 3. Electron Micrographs of Soil Distribution on Fabrics Having Different Crimp Levels

The appearance of a colored body is determined by light absorption, in which radiation energy is taken up and converted to heat, and by light scattering, which brings about a change in the direction or diffusion of the radiation.[7] Specular reflection occurs only from a smooth source and from objects which are large with respect to the wave length of the light. Since textile fibers are not considered to be smooth, color perception is explained using light scattering equations.

The ends of slender bodies, such as fibers, will scatter more light than the body. Thus, in a fabric made from yarns spun from staple fibers such as cotton, there is an inordinate fraction of light scattering from short lengths of fiber protruding from the yarn bundle. The increased scattering from these protruding lengths of fibers causes the viewer to perceive the fabric as being brighter or whiter.

It is not only the amount of scattering, but the direction of scattering which has an effect on appearance. A circular fiber will scatter light in the forward direction (or from 0 to 90 degrees) and will give a dull appearance. With light scattered in the backward direction, or at 90 to 180 degress, a darker, richer color will be obtained which will be better in masking the appearance of soil. It is this back scatter phenomenon along with the presence of increased scattering which causes a viewer to see the fiber and not the soil.

Scattering is thus a very important influence on how colors are perceived. Yarn size, fiber denier, yarn twist, and yarn crimp also determine how color is perceived. For example, in synthetic yarns, when the fiber denier is varied, the ratio of skin to core is also changed which leads to changes in a fiber's ability to accept dye.[3] Finer fibers have greater surface areas per unit volume. Accordingly, they exhaust the dye bath more rapidly. Since the dye will not penetrate to the core and there is a greater surface area to cover, finer fibers will not achieve the depth of color of fibers which are coarser. A fine yarn would behave similarly.

Yarn twist also plays an important role in determining the appearance of a fabric. The twist in a yarn is one of the factors that determines the way light is reflected from the surface of the yarn and thus how dark or light the fabric appears. When light strikes the surface of the fabric in the direction of twist, it is reflected from long, uninterrupted lines between the fibers. Fewer shadows are noted and the fabric appears brighter and lighter in color.[5]

Twist determines to a great extent the luster of the yarn. The luster of the yarn may be subdued or developed according to the degree of twist imposed. The twist tends to directly counteract the reflectivity of the rays of light. With greater twist, the fiber helix angle measured with respect to the yarn axis will increase, and the yarn will be duller in appearance.

Twist not only is important in relation to optical properties, but also has an effect on geometric properties. When a yarn is twisted, the fibers will be oriented in such a way as to make a certain helix angle with the yarn axis.[6] This angle may vary along the length of the yarn. When twist is inserted in the yarn, the effect will be to increase the inclination of the fibers with respect to the yarn axis and to increase the lateral pressure exerted by the fibers over one another. The result is that the fibers are held more firmly together. The outcome of this increase in twist is that soil particles may be prevented from penetrating into the inner layers of yarn.

Twist has other effects on soiling behavior. The shearing effect of the increased lateral pressure with increased twist tends to enlarge any fissures, cracks, or pits on the surface of the fiber.[6] These openings provide good locations for soil particles to become entrapped.

Both of these effects are negligible at low twists, but become more important as additional twist is inserted in the yarn.

Twist also directly affects the covering power of a yarn. As twist is increased within certain limits, the diameter of the yarn decreases thus decreasing the covering power.[9] This decrease in covering power will be further discussed with the effects of crimp in a yarn.

Yarn crimp is another important property which can possibly relate to soiling. Crimp is affected by yarn diameter, fabric construction, and yarn stiffness. With an increase in yarn diameter, less crimp per constant length will occur. With an increase in yarn stiffness, less crimp will also occur.

Yarn crimp like yarn twist, has effects on optical properties of fabrics. This results from differences in light scattering caused by differences in fabric geometry. The effects of short lengths of fibers protruding from the yarn bundle in increasing the amount of light scattered, has already been discussed. This scattering from yarn crimp is less than that resulting from short lengths of fiber protrusions. This is because the fiber lengths have small radii of curvature while the bends in a crimped yarn have large radii of curvature. Although of less significance than the number of short fiber lengths, crimp provides an additional source of light scattering.

The yarn crimp also affects the areas in which soil particles can be entrapped. With greater crimp, the yarn crowns will receive more tension than other areas of the yarn. The fibers will be forced closer together to decrease the strain. It will be more difficult for soil to penetrate.

The effects of crimp are not independent of other yarn properties. The effects of yarn twist, yarn diameter and crimp as they interrelate can help explain the results obtained in this thesis.

The lack of reflectance differences found in this experiment is probably related to the effect of these yarn and fabric variables on light scattering. It is believed that yarn twist was not significant in producing soiling differences because of the counteracting effects of soil deposition and reflectance. As yarn twist is increased, less soil particles are able to penetrate the yarn because the spaces between the fibers decrease. The reflectance should increase as a result of the lower amount of soil. As yarn twist increases, the luster of the yarn will also be subdued and will cause a decrease in reflectance. The overall effect of the soil particles and twist is to cancel any individual effects.

Furthermore, the size of the soil particles may have prevented any significant differences in reflectance to be observed. In this experiment, the soil particles were relatively small as compared to the yarn size. The particles averaged about 40 microns. Therefore, regardless of which experimental variables in yarn structure were produced, it is possible that the tiny soil particles were able to penetrate the yarns with the greatest amount of twist as easily as the yarns with the least amount of twist.

The results of yarn count can be explained similarly. As yarn cotton count increases and diameter of yarn decreases, there will be a decrease in reflectance because of background effects. In this experiment, the number of warp and filling yarns per inch was kept constant in all fabrics. Thus, as the yarn count increases, there will be more open areas for the light to hit background areas. The light will go first through the fabric and then be trapped in the second layer of the background fabric. The light scattered will be reduced and the reflectance values of the fabric with a greater yarn count should be decreased. However, with an increased yarn count, fewer soil particles will be absorbed. This will increase the reflectance. Thus, the two effects could possibly counterbalance each other.

In this case too, the size of the particle will also serve to affect all the yarn counts in the same way. The small size of the soil enables it to be distributed equally regardless of the yarn count.

The results obtained on samples having yarn crimp differences can possibly be explained by the effects of both soil deposition and reflectance. After soiling, more soil and decreased reflectance values were noted on samples of greater filling crimp. However, after laundering, the samples of greater crimp had higher reflectance values and less soil. Thus, the samples of higher crimp appeared to soil more and were cleaned better.

With a fabric of increased crimp, it would have been expected that the tension in the uppermost portion of the yarn crown would allow less soil to penetrate. This increased tension would cause an increase in reflectance. However, the increased tension does not prevent soil from being deposited on the surface of the yarn. It was observed in the micrographs that samples with greater crimp did have more soil deposited on the surface. Also, the samples of less crimp would have less surface tension which would enable more soil to penetrate the yarns where it might not be detected.

After laundering, unlike after soiling, the samples of greater crimp had greater reflectance values. The possible explanation is that while samples of greater crimp had more soil deposited on the yarn surfaces, this soil was easier to remove than the entrapped soil of the samples of lower crimp. Thus, the samples which had lower reflectances after soiling, would have higher reflectances after laundering. Also, because of the greater tension and reduced fiber helix angle at the crown, there will be more reflectance and thus an increased reflectance value. Another possibility for the significance of crimp, even when the soil particles were very small, is that the increased tension was located only in one specific area of the yarn crowns. The twists in a yarn are located throughout the yarn. Thus, in a crimped yarn there will be different areas in which soil can either penetrate or not and thus be significantly different.

It must also be remembered that in any experiment there is the possibility that results are caused by experimental error or chance. Since only one of the three variables was significant, the possibility of experimental error was considered. Even though it is considered, it is probably not the explanation for the statistical significance of the soiling differences associated with the filling crimp effects. It is to be noted that after laundering, filling crimp was again the only statistically significant variable. Thus, if the warp tension was significant in the soiled samples as a result of chance, it would be unlikely that after laundering it remained significant again.

CHAPTER IV

CONCLUSIONS

The importance of light scattering has already been discussed. It has been stated that short fiber lengths protruding at the yarn surface are the chief source of light scattering. While twist and yarn count are factors in influencing the appearance of a fabric, the scattering produced by fiber protrusions counteracts the effects of twist and yarn count. The effect of soil particles being small relative to yarn structural characteristics is that neither yarn twist nor yarn count will be associated with soiling differences.

The effects of yarn crimp in fabrics is to increase the resistance of soil particles to penetration of the yarn with increased crimp. An increased number of particles are therefore deposited on the crowns of the yarns and result in increased apparent soiling.

CHAPTER V

RECOMMENDATIONS

There was not a large difference in the amounts of filling crimp obtained from the two levels of warp tension. The filling crimp was significant in producing soiling differences. It would be useful if further investigations of the effect of crimp on soiling could be made. In such an investigation, greater crimp differences should be obtained so that more definitive results can be obtained.

It was observed in this work that sample drying after soiling caused reflectance variations. This result was seen with the samples that were dried while suspended vertically. It is possible that the problem of reflectance variation in commerically available soil cloth is a result of soil migration caused by the drying method. An examination of the effects of soil migration through layers of wet, soiled fabric should be made.

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